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STATE-OF-THE-ART REVIEW
OF
LOW-COST COLLECTOR TECHNOLOGIES

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JUNE 1981

CAPTAIN WILLIAM A. TOLBERT, P.E.

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Light-Weight	Thin-Film	Reliability
Heliostats	Polymers	Military

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report provides a brief but concise review of low-cost solar collector technologies and their potential for application within the military. The report covers low-cost, light-weight concepts for flat-plate collectors, parabolic trough collectors, heliostats and parabolic dish collectors. In addition several criteria were evaluated with respect to low-cost collector technologies. These included reliability, maintainability, survivability, mobility/erectibility, environmental impact and economics. Research and development requirements and ongoing activities were also summarized. This report

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documents one of several ongoing state-of-the-art reviews of solar technologies performed by an Air Force liaison office with the Department of Energy.

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PREFACE

This report documents work performed to determine the state-of-the-art of selected solar technologies. The report is based on literature available in the public domain and additional information and data obtained from representatives from various national laboratories and industries.

Opinions expressed in this report are those of the author and do not reflect the view of the Department of the Air Force or the Department of Energy. Citation of trade names or manufacturers does not constitute an official endorsement or approval of the use of such products.

This report has been reviewed and approved for publication by the Department of Energy and is releasable to the National Technical Information Service (NTIS) where it will be available to the general public and foreign nations.

William A. Tolbert

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STATE-OF-THE-ART TECHNOLOGY REVIEW
of
—LOW COST COLLECTOR TECHNOLOGIES—
by
Captain William A. Tolbert, P.E.

1.0 INTRODUCTION

In the past, research and development emphasis in the design of solar collectors (i.e., flat plate, trough, dish, heliostat, etc.) has centered on collector performance. Using this approach, collectors have been designed to meet strict reliability, maintainability, and durability criteria while converting solar energy into heat by using the most efficient, often highly technical methods. This approach has produced collectors which incorporate sophisticated materials, heavy components, expensive seals and complicated controls. Using this approach, the reduction of costs after the working systems have been developed has proven extremely difficult.

Recently, several new research and development efforts have taken an approach which is fundamentally different. Rather than building efficient, durable collectors that work and then trying to reduce their cost, low-cost collector technologies start with collectors that are inherently inexpensive and try to improve their performance and lifetime. Low-cost collector R&D uses as its prime design consideration the cost per unit of delivered energy. This methodology allows for decreased performance so long as the decreased costs of the collector system are proportionally greater. Low-cost collectors designed to meet this criteria tend to have low-mass, low-cost materials, low installation costs, streamlined system design, etc.

Current experience with low-cost collectors indicates that significant reductions in initial cost (75% and better) can be achieved with small decreases in component performance. In addition, the reduced cost allows for some collector systems to be used in energy applications where lowered performance may have little if any negative impact (Figure 1.0).

As a result, low-cost collector research and development programs are producing solar collector systems which have the potential of being more economically competitive in conventional military applications. In addition,

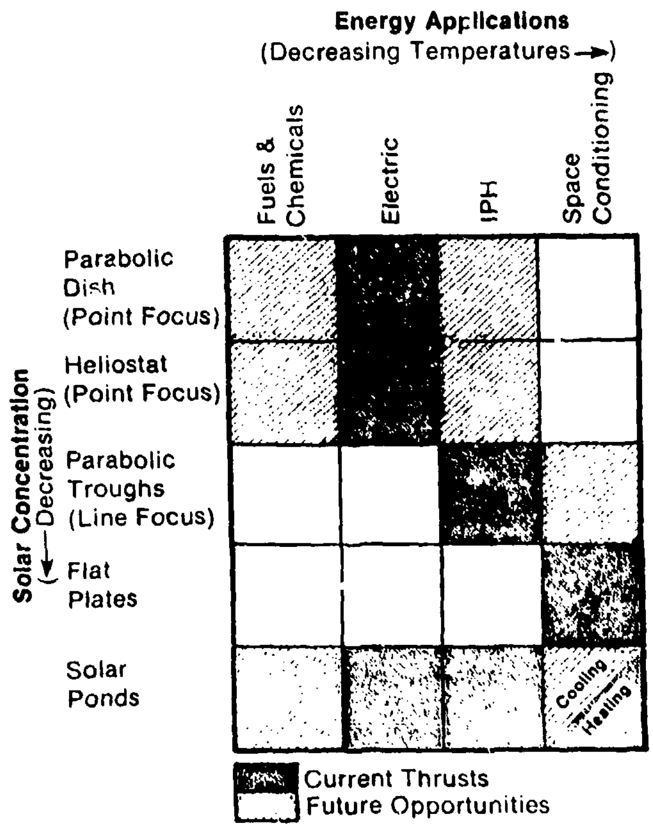

Figure 1.0 Solar Thermal Systems and Applications

many of these systems are so lightweight, portable, and easily erectable that they open up several significant opportunities for air mobile and tactical military applications.

2.0 OVERVIEW OF THE TECHNOLOGY

Low-cost collector technology incorporates work in various separate solar technologies including flat plate collectors, solar ponds, parabolic troughs (line focus), heliostats (point focus), and parabolic dishs (point focus). Each of these solar technologies could be the subject of a complete state-of-the-art review. Therefore, only the low-cost collector aspects of each of these technologies will be discussed in any detail in the following sections of this

paper. In most cases, specific examples of actual units under research and development will be highlighted although no product endorsement is either stated or implied.

2.1 Flat Plate Collectors

Flat plate collectors are non-concentrating units which absorb solar energy and transfer the energy to a working fluid or air. The flat plate collector industry is currently producing collectors which are bascially similar in design. Although some variations do exist, the current models reflect a design which has been found to be durable and solves the three interrelated problems which all flat plate collectors face. These are stagnation, freezing, and corrosion. Unfortunately, the design which has proven best (i.e., copper tubing, metal absorbers, metal frames, glass covers, etc.) has also proven expensive to build. In addition, future costs are not likely to come down significantly because this design is materials intensive.

Low-cost flat plate collector (LCFPC) technology takes the approach of avoiding stagnation by the design of the collector and by using materials which can alleviate the problems of corrosion and freezing. Some LCFPCs use foamglas or modified concrete block configurations to provide low-cost "air heaters". Most LCFPCs, however, have turned to using high-performance, thin-film polymers (i.e., polyester, plastics, etc) which are combined using high-speed printing, laminating, and extruded processes to make flexible absorber and glazing structures. The advantages of these materials include their flexibility, strength, abrasion resistance, light weight, corrosion resistance, and low costs (per square foot). Specific examples of three LCFPCs follow.

2.1.1 Acurex Corporation Collector

The Acurex LCFPC shown in Figures 2.1.1-1 and 2.1.1-2 is based on the use of thin polymer materials to make a flexible absorber structure. Here two layers of polyester (Hytrel) are sealed together to form flow channels, then the outer layers are laminated. The uppermost polyester layer is black and UV (ultra violet) stabilized. The absorber is nominally 12 mils thick and is fabricated in rolls at the rate of 100 to 500 feet per minute. The prototype design uses corrugated plastic roofing material for backing and insulation and uses water as a working fluid (drain-down). Individual panels are attached to the roof with tie-down straps on the outer edges and use a clear polyester film as an overall glazing. The manufactured cost of this panel (including hardware and retail markup) has been projected at $\$2/ft^2$.

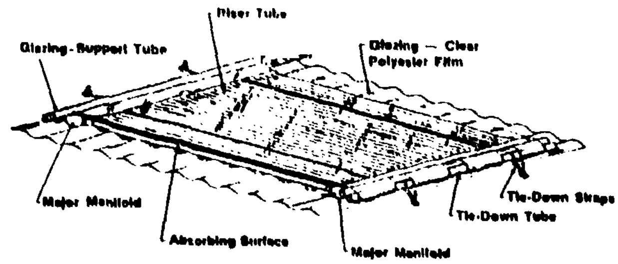

Figure 2.1.1-1 Acurex Collector

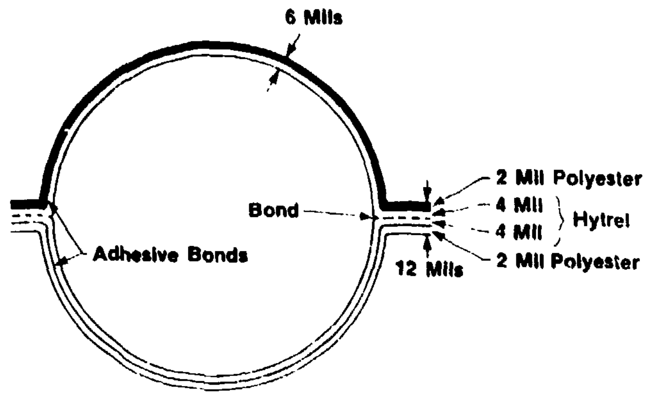

Figure 2.1.1-2 Cross Section of Acurex Absorber

2.1.2 Brookhaven National Laboratory Collector

The Brookhaven LCFPC shown in Figures 2.1.2-1 and 2.1.2-2 uses a double layer, thin-film absorber mounted in a lightweight steel housing. Each layer of film is composed of an aluminum foil laminated to a plastic film. Faced together, the plastic films are sealed to form flow channels between layers. The manifolds at top and bottom of the collector are lightweight tubing sealed between the film layers. Water is used as the heat transfer medium. The collector glazing is also a thin-film polymer. The Brookhaven collector can be manufactured for a little over $\$1/ft^2$ ($\$5/ft^2$

installed) and weighs less than ten pounds for a 20 ft^2 panel.

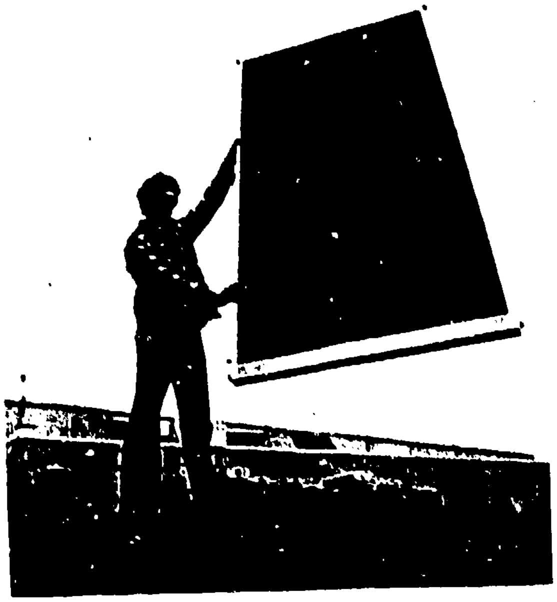

Figure 2.1.2-1 Brookhaven Collector

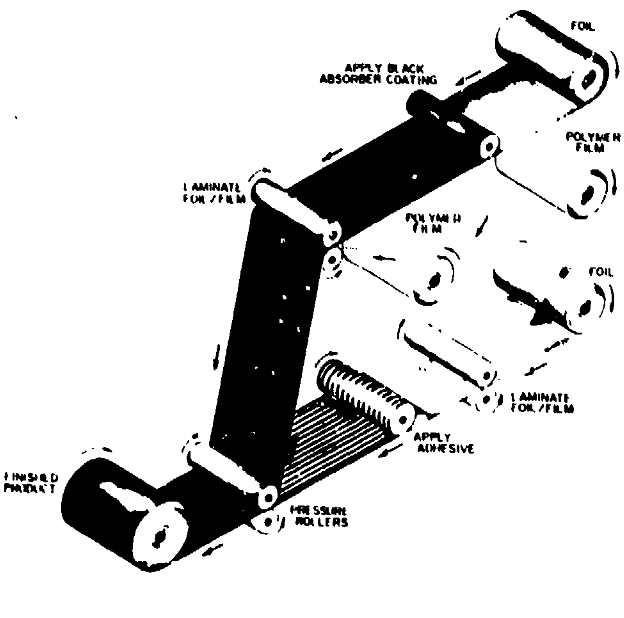

Figure 2.1.2-2 Brookhaven Absorber

2.1.3 Battelle Memorial Institute Collector

The Battelle LCFPC shown in Figure 2.1.3-1 is a low-temperature black liquid collector in which the solar radiation is absorbed directly into the "black liquid" heat transfer medium. This collector uses an extruded clear acrylic absorber which has a black liquid flowing within the extruded fluid channels. The collector also uses a foil faced back insulation and an additional acrylic glazing. Several solutions or suspensions of black liquids having almost 100% absorption across the solar spectrum have been tested in this configuration.

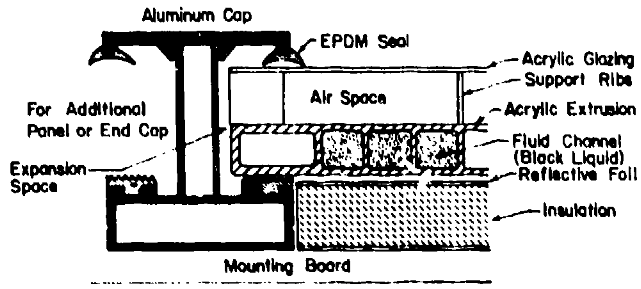

Figure 2.1.3-1 Battelle Collector Schematic

2.2 Solar Ponds

All solar pond technologies can be included in the area of low-cost collector technologies. Solar ponds (Figure 2.2-1) both collect and store solar energy and have high near-term potential for simple low-cost military application. Because of this, the area of solar ponds has been reviewed in detail in another state-of-the-art review document and will not be described here.

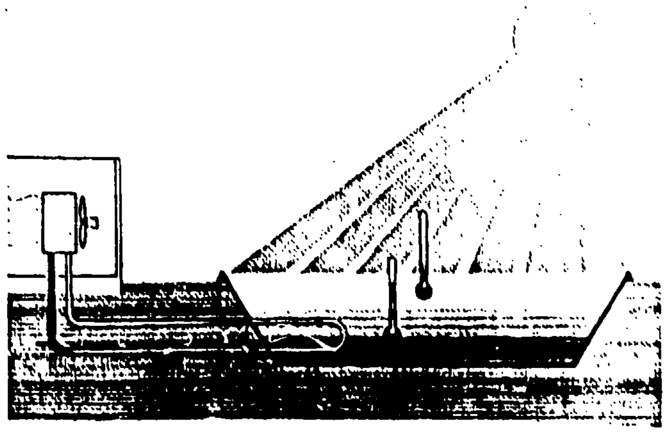

Figure 2.2-1 Salt Gradient Solar Pond

2.3 Parabolic Trough Collectors (Line Focus)

The four major components of a line focus parabolic trough concentrating collector are: concentrator, receiver, drive, and controls. Of these components the concentrator is generally the most expensive, accounting for approximately one-half of the total collector budget. Thus, the concentrator offers the largest potential for collector cost reduction of any single component. The development and use of lightweight, durable, and low-cost materials for concentrators, especially in combination with design innovations which decrease wind loads, can produce dramatic collector cost reductions.

Another area where line focus concentrating collector costs can be cut is installation costs. This can best be achieved through use of lighter weight concentrators. Lightweight collectors of five to ten feet in aperture width that can be lifted and installed by hand offer a significant improvement over current installation practices. Also, the minimization or elimination of the multitude of parts currently used for the support, drive, and control of concentrating collectors can result in significant installation cost reductions.

In the area of low-cost parabolic trough collectors (LCPTC) one innovative solution involves the use of an inflatable circular cylindrical concentrator fabricated from flexible metallized plastic films made of aluminized polyester or aluminum foil film laminates. In this approach (Figure 2.3-1), the inflated collector can achieve 3X concentrations with only weekly adjustments. Inflatable type low-cost collectors are being developed by the Monsanto Research Corporation and the Lawrence Livermore Laboratory.

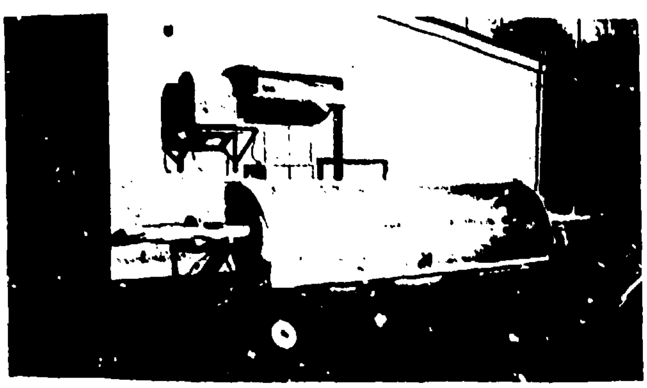

Figure 2.3-1 Monsanto Collector

2.3.1 Solar Energy Research Institute (SERI) Collector

The SERI LCPTC shown in Figures 2.3.1-1 and 2.3.1-2 adapts a more conventional design for parabolic trough systems and uses a concentrator which is fabricated out of a one inch paper honeycomb/melamine sandwich and is faced with an aluminized acrylic. The five foot aperture by 12 foot length of the concentrator is currently limited by available stock sizes of melamine. The experimental trough system located at SERI consists of three lightweight, low-cost concentrators that are chorded rim to rim across the aperture with cables that provide structural strength and a method for gang driving (adjusting) the concentrators. The use of gang drives reduces the effects of wind loading on the reflector and simplifies the drives needed for each individual collector to sense and track the sun and minimizes capital and installation costs. The cost of the SERI LCPTC is estimated at $5/f^2 for concentrator materials, aluminized acrylic reflector, receiver materials, mounting structure and controls.

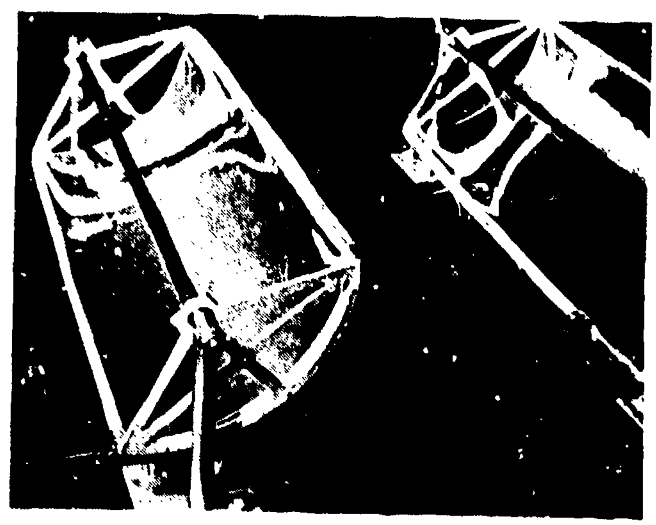

Figure 2.3.1-1 SERI Collector

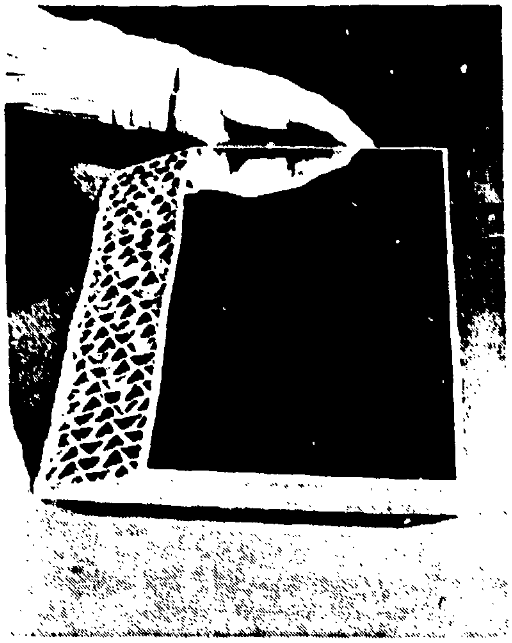

Figure 2.3.1-2 Honeycomb/Melamine Section

2.4 Heliostats (Point Focus)

Heliostats are individually guided mirrors which redirect the sun's energy to a receiver mounted in a central area. In the receiver, the energy is absorbed into a circulating (heat transport) fluid and is either used to power a turbine, an industrial process, or is transferred to a storage system for use during a later period. Heliostat costs can constitute 50% or more of the cost of a central receiver system and offer substantial opportunity for system cost reduction.

First and second generation heliostats are characterized by their extensive use of mirrored glass, heavy support structures, and complicated focusing and control mechanisms.

Third generation systems are currently under development which attempt to reduce the complexity and cost of heliostats. An excellent example of an innovative low-cost heliostat design was developed at SERI. The SERI design shown in Figures 2.4-1 incorporates a reflective surface (thin mirror glass or aluminized acrylic) bonded to a framed, stretched membrane. Currently a standard 12 foot diameter trampoline serves as the frame and membrane and results in a heliostat with a ten foot diameter reflective surface that weighs 288 pounds and costs approximately $\$8/f^2$. In addition, the SERI concept incorporates a four-cable gang drive focusing system that also serves as the mounting system for the heliostats. The cable control and mounting system (Figure 2.4-2) requires only two support structures (one at each end of a heliostat row) and greatly reduces site preparation (grading, leveling, etc.).

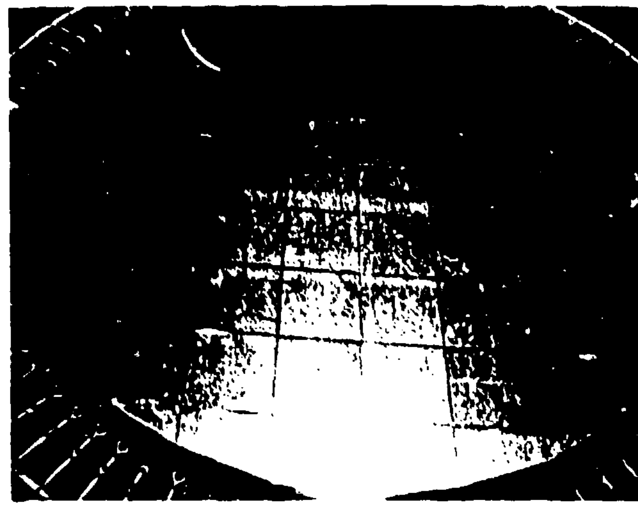

Figure 2.4-1 SERI Heliostat

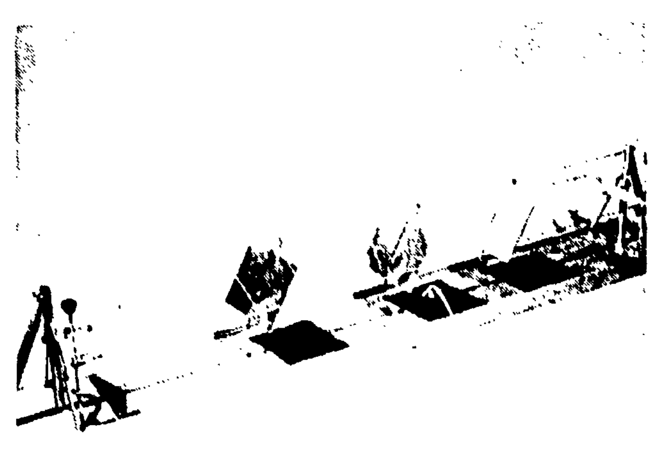

Figure 2.4-2 SERI Mounting System

2.5 Parabolic Dishes (Point Focus)

Parabolic dishes are the principal component of a small two-axis tracking solar thermal power system which focuses the energy of the sun on a

small receiver at the focus of the collector. The receiver can be a simple heat exchanger which transfers the energy to a working fluid or it often is a small collector-mounted heat engine (either Brayton or Stirling cycles). Conventional parabolic dish systems vary in size and configuration but often are substantial in size and weight (i.e., 33 ft in diameter and 50,000 lbs or more). Although conventional parabolic dish systems have used lightweight metals and mirrors to a great extent, they still remain relatively massive and expensive to produce and construct.

To counter this trend, several efforts are underway to develop innovative low-cost parabolic dish collector (LCPDC) systems which utilize thin films and lightweight construction. Two concepts which typify this approach are shown in Figures 2.5-1, 2.5-2, and 2.5-3.

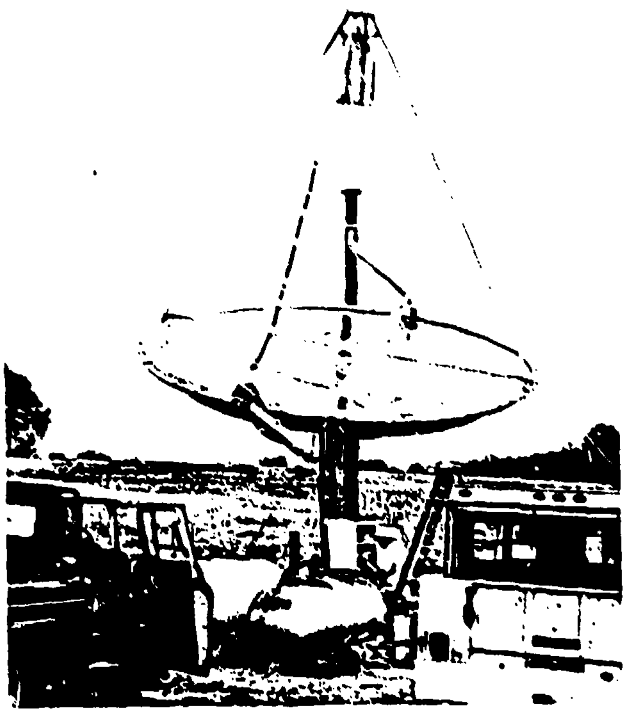

Figure 2.5-1 Summit Ind. Dish

The Summit Industries' membrane dish uses a polyester membrane, coated on one side with an aluminized reflective film. The film is stretched over a steel angle rim along with a second membrane that forms the back covering. An aluminum space frame provides the volume between the two membranes. A vacuum pump draws air from this volume, forcing the reflector into a concave shape. The shape is maintained by a set switch, which keeps the focal point at the receiver by activating the vacuum pump whenever the pressure differential falls below the required value. The concentrator and support structure are designed to "snap" together in the field and the finished 25-foot diameter model (Figure 2.5-1) will weigh less than 3,000 lbs.

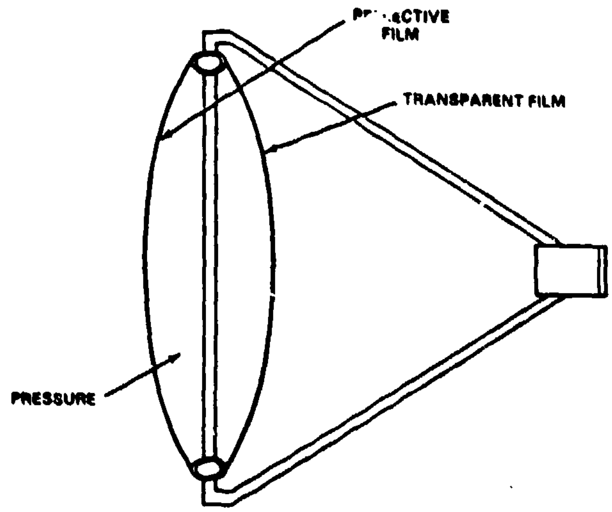

Figure 2.5-2 AAI Dish Section

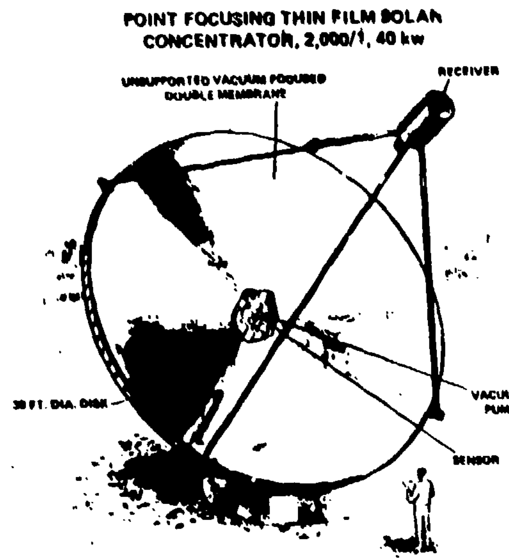

Figure 2.5-3 AAI Corp. Dish

The AAI stretched thin-film concentrator is similar to the Summit Industries concept except that the concentrator uses a 30-foot diameter metal backed dish with the reflective membrane on the front drawn down by a partial vacuum (Figure 2.5-2). The AAI concentrator concept also uses a six-wheeled, tracked turntable mounting system in lieu of a pedestal mount.

3.0 POTENTIAL APPLICATIONS

There are two major categories of application for low-cost collector technologies. These include conventional applications where space conditioning, industrial process heat, or power are required and solar applications are only constrained by simple economics (i.e., LCC, SIR, etc.), and tactical and strategic applications where air mobility, erectability and self-sufficiency have significant military unique value. It is conceivable that low-cost collector technology has application to virtually every terrestrial military requirement for thermal or electrical energy.

4.0 DISCUSSION

In order to accurately assess the specific application potential to the military of low-cost collector technology, several criteria should be further discussed. In reviewing these criteria, it should be understood that the majority of these low-cost collector technologies are still under research and development and detailed performance and cost data bases are relatively limited. A detailed analysis of these criteria relative to solar ponds is also contained in a separate state-of-the-art review.

4.1 Reliability

For the most part, all of the low-cost collector technologies should produce systems at least as reliable as their conventional counterparts. This is due in part to their simplicity of design and in part to their ease of component replacement. Current reliability concerns surround the lifetimes of the materials used in low-cost collectors. Specific areas of concern include UV degradation, embrittlement, discoloration, and cleaning problems.

4.2 Maintainability

The level of maintenance required to keep low-cost collectors in operation has not yet been confirmed. On the one hand, many of the thin films being used are susceptable to damage and degradation. On the other hand, many of the components are easily and inexpensively replaced. In addition, because of the reduced use of metals many corrosion problems will be reduced. Projected lifetimes of the various collectors and components vary from five to 20 years with some data confirming ten-year lifetimes of specially treated polymer films. For the most part, both maintainability and reliabili' remain materials R&D issues at this point.

4.3 Survivability

The survivability of each solar technology varies considerably with respect to specific designs and other solar technologies. It is expected however that within a solar technology (i.e., parabolic troughs) that the low-cost collector system would be as survivable as its conventional counterpart. In fact, the increased flexibility of many low-cost collector components and their easy replacement may actually enhance the survivability of low-cost collector systems under some scenarios. For example, if the SERI heliostat design using aluminized acrylic reflective surface was penetrated by an object a reflective "patch" could quickly be applied. This would not be the case with a conventional mirrored glass heliostat.

4.4 Mobility/Erectibility

Low-cost collector systems are almost always lighter in weight than their conventional counterparts and require significantly less equipment and fewer tools for field erection.

As an example, conventional flat plate collectors can weigh 10 lb/ft^2 to 15 lb/ft^2 and require substantial support structures and installation equipment. Low-cost flat plate collectors weigh 0.5 lb/ft^2 or less and can be installed by an individual with hand tools. As another example, a low-cost parabolic dish collector (25-foot diameter) weighs less than 3,000 lb, can be compactly delivered to a site, and can be completely erected by four persons in five days or less.

Many of the low-cost collector systems could easily be transported in lightweight "kits" that could be erected by unskilled labor on undeveloped sites. Such "kits" could improve the self-sufficiency of mission-oriented support facilities such as air mobile field hospitals and could halve the logistical requirements for fuel.

4.5 Environmental Impact

Since low-cost collector systems are not as materials intensive as conventional solar systems, the energy resources required to produce them is significantly reduced.

Other environmental impacts parallel those of conventional solar systems.

4.6 Performance

The value of lower cost collectors would be reduced if proportional reductions in performance were also encountered. This is not the case. The results of recent research in all of the low-cost collector technologies documents that performance reductions are minimal and that most low-cost collector system performance is comparable with that of their conventional counterparts. This must still be documented in long-term field applications.

4.7 Economics

By definition, low-cost collectors have as their goal reduced costs. The table below compares conventional collector/systems costs with those being attained by low-cost collectors systems. Solar pond economics has no conventional comparison.

	Low Cost System ft^2	Conventional System ft^2
Flat Plate (Installed)	\$5-6	\$30-40
Solar Ponds	\$4-10	---
Parabolic Troughs (Installed)	\$10-15	\$20-30
Heliostats (Installed Comp.)	\$10-15	\$40
Parabolic Dish (Installed System)	\$8-40	\$80

In addition to the reduction in materials costs, installation costs will also normally be reduced for low-cost collectors systems.

These significant reductions in first costs coupled with comparable lifetimes and performance could make low-cost collector solar systems competitive with conventional non-renewable energy systems <u>today</u>. Many of the solar retrofit projects which do not qualify for today's congressionally funded programs (i.e., MCP, ECIP, etc.) would be easiliy justifiable if cost reductions of 50% to 80% can be achieved through the use of low-cost collector technology.

5.0 OPERATIONAL EXPERIENCE

Relatively limited data exists on the performance of any of the low-cost collector technologies although significant research has been done on the materials which form the basis of many of the designs. With the exception of low-cost heliostats, prototype systems are currently in operation and actual performance closely correlates with predicted performance.

In many cases, the technologies incorporated in the manufacture of low-cost collectors are proven technologies which have been adapted to a solar application.

6.0 CURRENT STATUS

At this point in time, low-cost collector technologies would be classified in the research and development stages. This varies to a certain extent based on the specific solar technology involved and the level of development on individual components or systems. The prototype components or systems described in this paper have all been developed within the last three years and only limited performance data is available yet. However, significant materials research and development efforts are currently underway in support of low-cost collector technologies.

It is possible that functional prototype solar energy systems using low-cost collector technology can be applied today to meet conventional military requirements. However, none of the systems described in this paper are suitable

for large-scale military-wide deployment or small-scale air mobile applications without additional engineering development.

7.0 R&D ORGANIZATIONS/ACTIVITIES

Several national institutes and laboratories have programs which include low-cost collector R&D activities. Principal among these is the Solar Energy Research Institute in Golden, Colorado. Others include: Brookhaven National Laboratory, Jet Propulsion Laboratory, Battelle Memorial Institute, Sandia Laboratories, and Lawrence Livermore Laboratory.

Substantial development work is also underway within various sectors in private industry.

8.0 CONCLUSIONS

Low-cost collector technologies are relatively new and as yet have not received very much visibility within national programs. Despite this fact, sufficient prototype systems, components, and concepts exist to document the substantial cost and weight reductions which are possible using existing thin film technologies and innovative concepts. This substantial reduction in initial system costs gives low-cost collector technologies the potential for shattering the economic feasibility threshold for military applications and of also providing solar thermal and electrical systems which may be ideally suited for air mobile military applications. In short, low-cost collector technologies should have significant value to the military.

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